Analog IC Design: Differential Opamp

30/04/14

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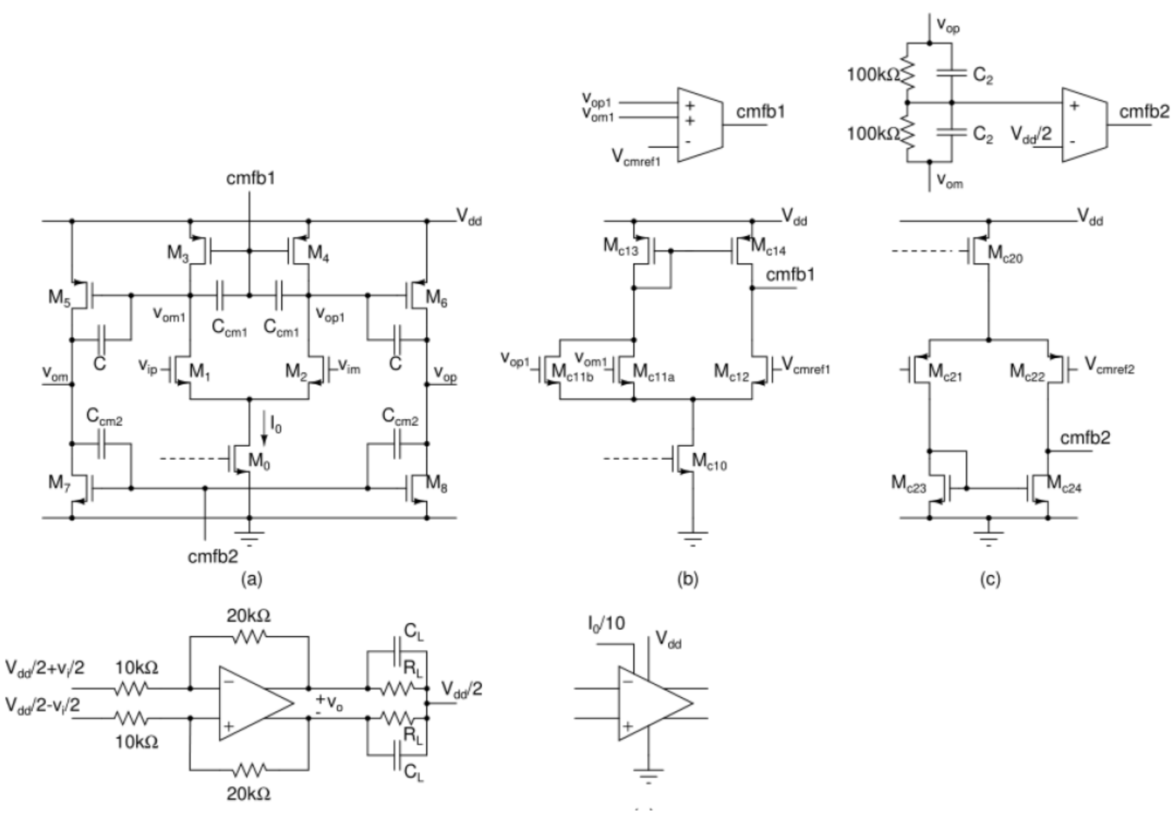
Platform: LT Spice

Procedure: With the given specifications, I performed a theoretical analysis of the differential opamp. I tried to get as many parameters as possible from the conditions and fixed other parameters to get the initial solution. I then modified the initially assumed values of certain parameters to come up with a design that satisfies all the given specifications.

Circuit:



Theoretical Analysis:

Specifications desired :

CL 3-dB B.W = 10 MHz

CL Gain = 2

PM = 60° for CMFB1, CMFB2 & Differential loops.

Given :

$R_L = 5\ k\Omega$

$C_L = 3\ pF$

CMFB 1

$$\omega_u = \frac{g'_{mc_1}}{C_{M_1}} \qquad p_2 = \frac{g_{m3}}{g_{m5} R_L C}$$

(assumed $R_L << r_{ds5}, r_{ds7}$)

PM = 60°

$$\Rightarrow \quad \frac{g'_{mc_1}}{g_{m3}} \frac{C}{C_{M_1}} \cdot g_{m5} R_L = 0.57735$$

Fix $\quad g_{m3} = 10\ g'_{mc_1}$

$$\Rightarrow \quad \frac{C\ g_{m5} R_L}{C_{M_1}} = 5.7735 \qquad \text{— (1)}$$

CMFB 2

$$\omega_u = \frac{g_{mc21}}{C_{M2}} \qquad p_2 = \frac{g_{m7}}{C + C_L}$$

$PM = 60^\circ$

$$\Rightarrow \frac{g_{mc21}}{g_{m7}} \frac{(C + C_L)}{C_{M2}} = 0.57735$$

Fix $g_{m7} = 10\ g_{mc21}$ — ②

$$\frac{C + C_L}{C_{M2}} = 5.7735$$

Differential Loop

$$\omega_u = \frac{g_{m1}}{C} \qquad p_2 = \frac{g_{m5} \times \frac{C}{(C + C_{M1})}}{C_L + C_{M2}}$$

$$\frac{g_{m1}}{g_{m5}} \frac{(C_L + C_{M2})}{C \times \left(\frac{C}{C + C_{M1}}\right)} = 0.57735$$

Fix $g_{m5} = 10\ g_{m1}$

$$\Rightarrow \frac{(C + C_{M1})(C_L + C_{M2})}{C^2} = 5.7735 \quad \text{— ③}$$

If we assume $C_{M1} << C$, we get a set of ~~solution~~ values which later contradicts with this assumption.

So

$$\omega_{3\text{-}dB} = \frac{g_{m1}\, f}{C} = 2\pi \times 10 \times 10^{6} \quad — (4)$$

$$f = \frac{1}{2}$$

Fix all $V_{Dsat\,NMOS} = 0.15\,V$

all $V_{Dsat\,PMOS} = 0.25\,V$

After solving iteratively and validating assumptions step-by-step, I came up with following set of values:

$C = 1\ pF$

$C_{CM2} = 0.8\ pF$

$C_{CM1} = 2\ pF$

$6\, g_{m_{C12}} = g_{m3}$

$10\, g_{m_{C21}} = g_{m7}$

$10\, g_{m1} = g_{m5}$

$R = 0.79365\ k\Omega$

$R_{cm1} = 13.23\ k\Omega$

$R_{cm2} = 0.4762\ k\Omega$

From (4)

$$g_{m_1} = 0.126 \text{ mS} = g_{m2}$$

$$g_{m5} = 10\, g_{m_1} = 1.26 \text{ mS} = g_{m6}$$

Choosing $V_{Dsat_N} = 0.15\text{ V}$, $V_{Dsat_P} = 0.25\text{ V}$

$$0.126 = \frac{2 \times \frac{I_o}{2}}{0.15} \Rightarrow I_o = 18.9\ \mu A$$

$$g_{m3} = \frac{\frac{2 \times 18.9}{2}}{0.25} = 0.0756 \text{ mS}$$

$$g'_{mc_1} = g_{mc_{11a}} + g_{mc_{11b}} = \frac{g_{m3}}{6} = 0.0126 \text{ mS}$$

$$\Rightarrow g_{mc_{11a}} = g_{mc_{11b}} = 0.0063 \text{ mS}$$

$$g_{mc_{12}} = 0.0126 \text{ mS}$$

$$0.0126 = \frac{2 \times \frac{I_{cm1}}{2}}{0.15} \Rightarrow I_{cm_1} = 1.89\ \mu A$$

$$g_{mc,3} = \frac{1.89}{0.25} = 0.00756 \text{ mS} = g_{mc,4}$$

$$g_{m5} = 1.26\ mS = g_{m6}$$

$$\Rightarrow \quad 1.26 = \frac{2 \times I_2}{0.25}$$

$$\Rightarrow \quad I_2 = 157.5\ \mu A$$

$$g_{m7} = \frac{2 \times I_2}{0.15} = 2.1\ mS = g_{m8}$$

$$g_{mc_{21}} = \frac{g_{m7}}{10} = 0.21\ mS$$
$$= g_{mc22}$$

$$\Rightarrow \quad 0.21 = \frac{2 \times \frac{I_{cm2}}{2}}{0.25}$$

$$\Rightarrow \quad I_{cm2} = 26.25\ \mu A$$

$$g_{mc23} = \frac{2 \times \frac{I_{cm2}}{2}}{0.15} = 0.35\ mS$$
$$= g_{mc24}$$

$$g_{m0} = 2\, g_{m1} = 0.252\ mS$$

$$g_{mc_{10}} = 2\, g_{mc_{12}} = 0.0252\ mS$$

$$g_{mc_{20}} = 2\, g_{mc_{21}} = 0.42\ mS$$

$$R = \frac{1}{g_{m5}}, \quad R_{cm_1} = \frac{1}{g_{m_3}}, \quad R_{cm_2} = \frac{1}{g_{m7}}$$

Simulation

MOSi	V_{Dsat} (V)	I (μA)	g_m (mS)	$\frac{W}{L}$	L (μm)	W (μm)	g_{ds} (μS)
M_0	0.15	18.9	0.252	5.6	1.8	10.08	2.56
M_1	0.15	9.45	0.126	2.8	0.18	0.504	4.25
M_2	0.15	9.45	0.126	2.8	0.18	0.504	4.25
M_3	0.25	9.45	0.0756	4.032	0.18	0.726	1.85
M_4	0.25	9.45	0.0756	4.032	0.18	0.726	1.85
M_5	0.25	157.5	1.26	67.2	1.163	78.154	10.6
M_6	0.25	157.5	1.26	67.2	1.163	78.154	10.6
M_7	0.15	157.5	2.1	46.67	1.177	54.93	13.7
M_8	0.15	157.5	2.1	46.67	1.177	54.93	13.7
M_{c20}	0.25	52.5	0.42	22.4	1.8	40.32	32
M_{c21}	0.25	26.25	0.21	11.2	0.18	2.016	3.43
M_{c22}	0.25	26.25	0.21	11.2	0.18	2.016	3.41
M_{c23}	0.15	26.25	0.35	7.78	0.18	1.4	10.1
M_{c24}	0.15	26.25	0.35	7.78	0.18	1.4	10.1
M_{c10}	0.15	1.89	0.0252	0.56	4.3	2.4	7.27×10^{-2}
M_{c11a}	0.15	0.4725	0.0063	0.14	1.714	0.24	3.33×10^{-2}
M_{c11b}	0.15	0.4725	0.0063	0.14	1.714	0.24	3.33×10^{-2}
M_{c12}	0.15	0.945	0.0126	0.28	0.857	0.24	0.103
M_{c13}	0.25	0.945	0.00756 ~~0.0756~~	0.4032	0.6	0.24	8.75×10^{-2}
M_{c14}	0.25	0.945	0.00756	0.4032	0.6	0.24	8.64×10^{-2}
M_{b1}	0.15	1.89	0.0252	0.56	2.145	1.2	0.108
M_{b2}	0.15	1.89	0.0252	0.56	2.145	1.2	9.35×10^{-2}
M_{b3}	0.25	1.89	0.01512	0.8064	1.8	1.45152	9.6×10^{-2}

$$\text{DC Gain} = \frac{g_{m1}\, g_{m5}}{(g_{o1} + g_{o3})(g_{o5} + g_{o7} + G_L)}$$

$$= \cancel{93388}\ 130$$

$$\Rightarrow \text{DC Gain (dB)} = \cancel{39.4\ dB}\ 42.2\ dB$$

$$\text{DC } LG_{CMFB_1} = \frac{g_{mC12} \times (g_{m3} \times \cancel{2})}{(g_{o12} + g_{o13})(g_{o3} + g_{o1}) \times \cancel{2}}$$

$$\approx 82$$

$$\Rightarrow \text{DC } LG_{CMFB_1} = 38.27\ dB$$

$$\text{DC } LG_{CMFB_2} = \frac{g_{mC21} \times g_{m7} \times \cancel{2}}{(g_{o21} + g_{o23})(\cancel{g}\ G_L) \times \cancel{2}}$$

$$= 163$$

$$\Rightarrow \text{DC } LG_{CMFB_2} = 44.24\ dB$$

Input referred offset

$$\sigma_{os}^2 = \sigma_{V_{T_{1,2}}}^2 + \left(\frac{g_{m3}}{g_{m1}}\right)^2 \sigma_{V_{T_{3,4}}}^2$$

$$\sigma_{V_T} = \frac{A_{V_T}}{\sqrt{WL}}$$

$$\Rightarrow \sigma_{V_{T_{1,2}}}^2 = \frac{(3.5 \times 10^{-3})^2}{0.504 \times 0.18} = 0.000135$$

$$\sigma_{V_{T_{3,4}}}^2 = \frac{(3.5 \times 10^{-3})^2}{0.18 \times 0.726} = 0.00009374$$

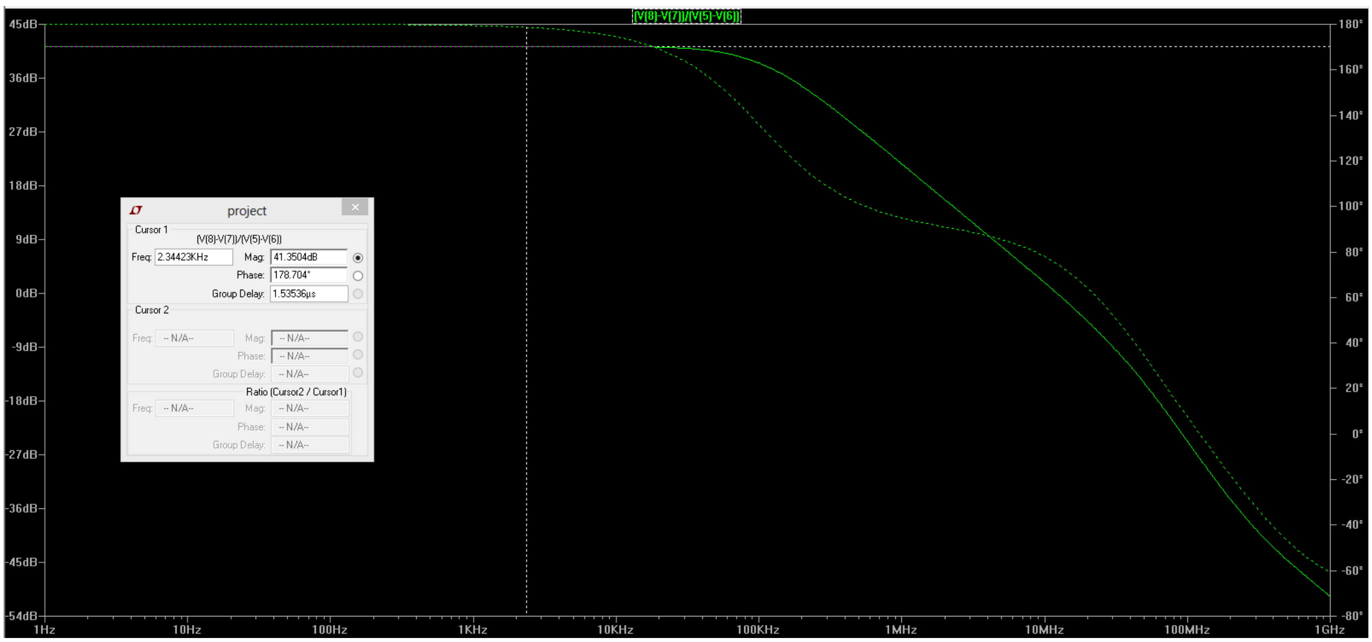
$$\therefore \sigma_{os}^2 = 1.687 \times 10^{-4} \ V^2$$

Spice Log file details at the end for matching

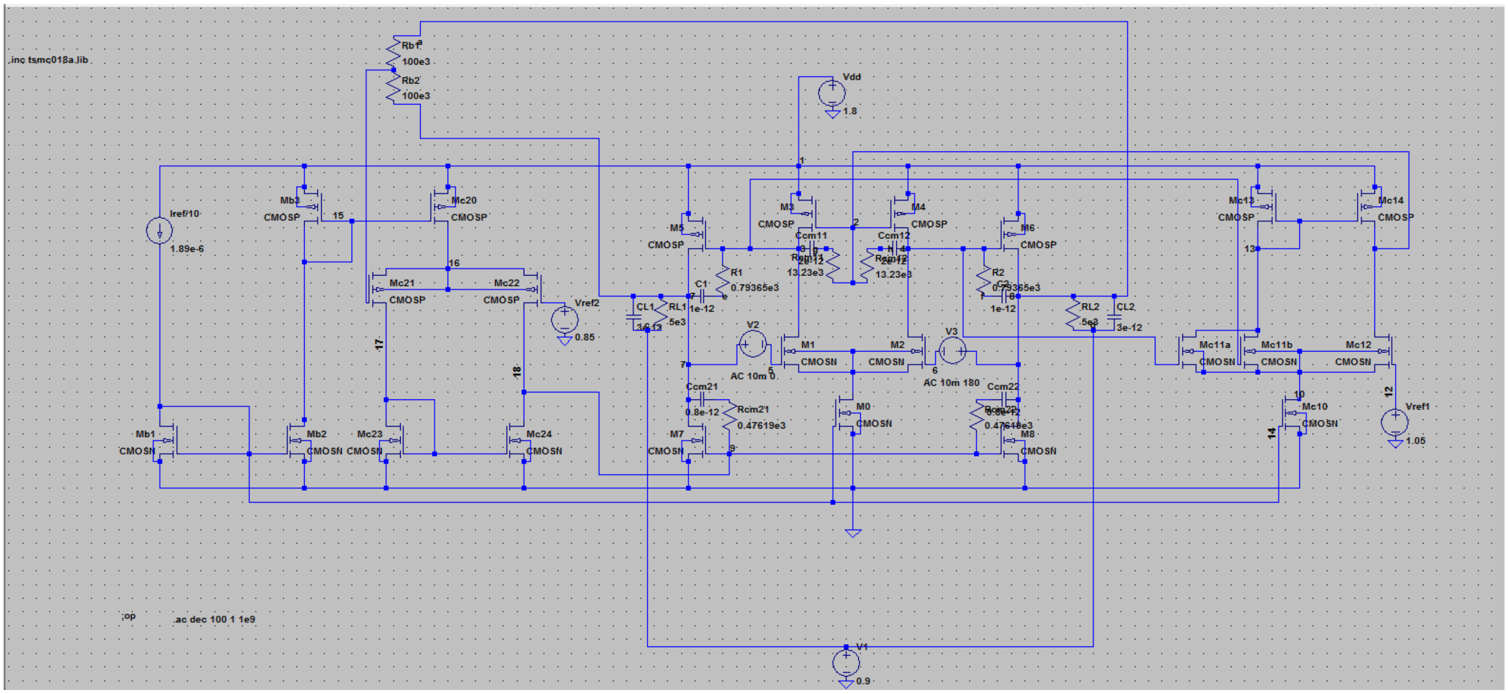
Observations:

- **Differential loop gain-magnitude and phase**
  Unity gain frequency = 12 MHz (taken feedback factor as 1)
  Open Loop Gain = 41.35 dB
  Phase Margin = 74.89 degree (plot adjusted to directly give PM)

(V(8)-V(7))/(V(5)-V(6))
45dB
36dB
27dB
18dB
9dB
0dB
-9dB
-18dB
-27dB
-36dB
-45dB
-54dB
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
-20°
-40°
-60°
-80°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
project
Cursor 1
(V(8)-V(7))/(V(5)-V(6))
Freq: 12.0226MHz
Mag: 131.021mdB
Phase: 74.8882°
Group Delay: 3.98111ns
Cursor 2
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--
Ratio (Cursor2 / Cursor1)
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--



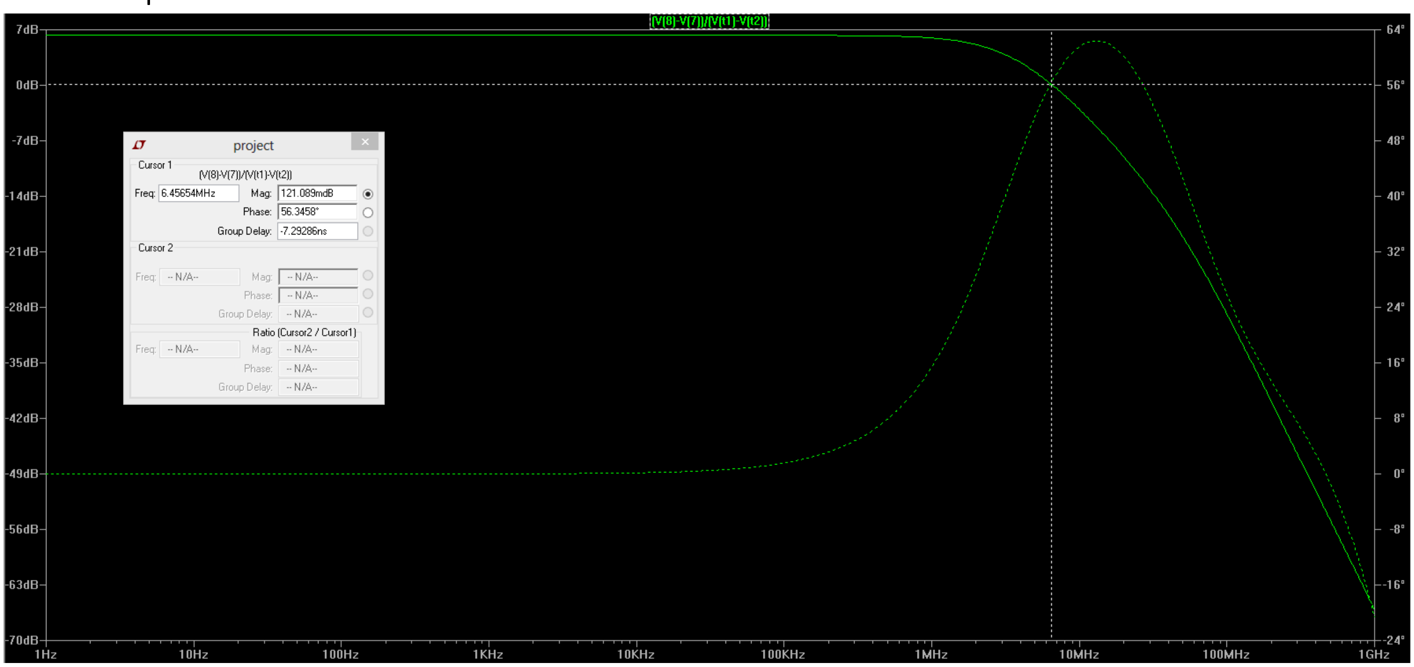
(V(8)-V(7))/(V(5)-V(6))
45dB
36dB
27dB
18dB
9dB
0dB
-9dB
-18dB
-27dB
-36dB
-45dB
-54dB
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
-20°
-40°
-60°
-80°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
project
Cursor 1
(V(8)-V(7))/(V(5)-V(6))
Freq: 2.34423KHz
Mag: 41.3504dB
Phase: 178.704°
Group Delay: 1.53536µs
Cursor 2
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--
Ratio (Cursor2 / Cursor1)
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--

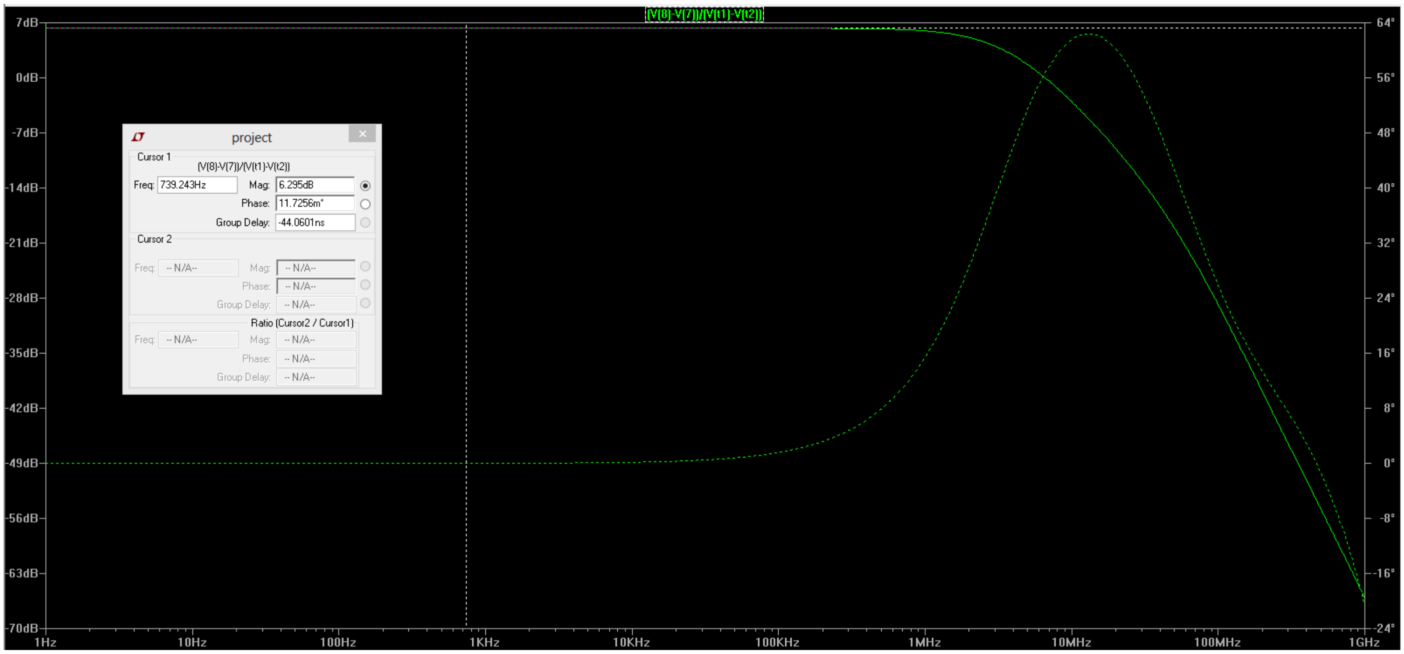


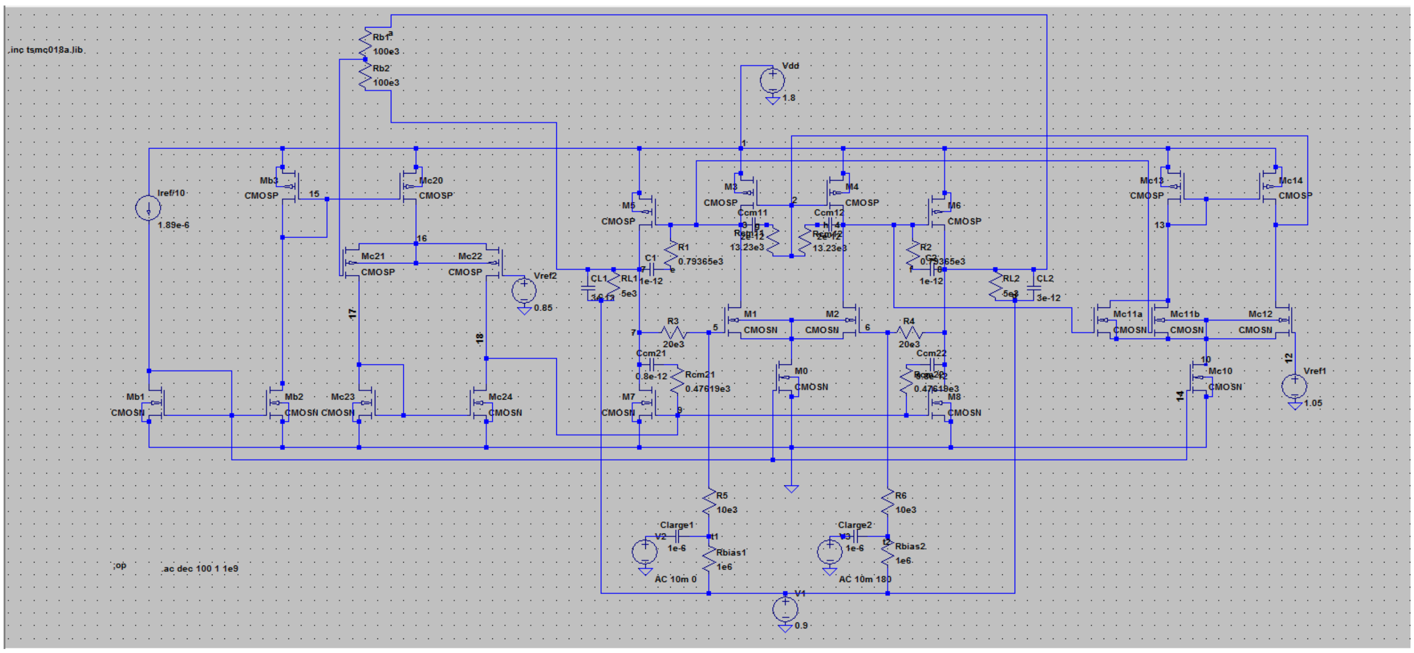
- **Differential closed loop gain-magnitude and phase**

  3-dB gain frequency = 6.46 MHz

  Closed Loop Gain = 6.295 dB





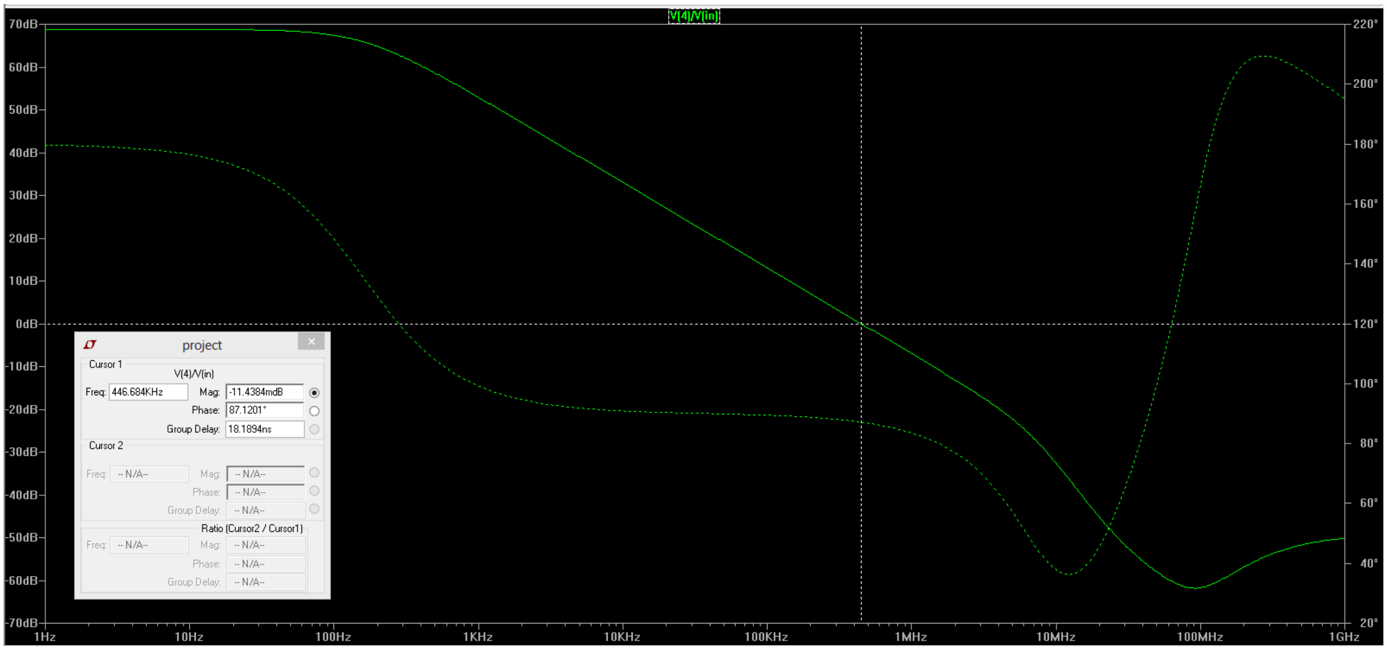


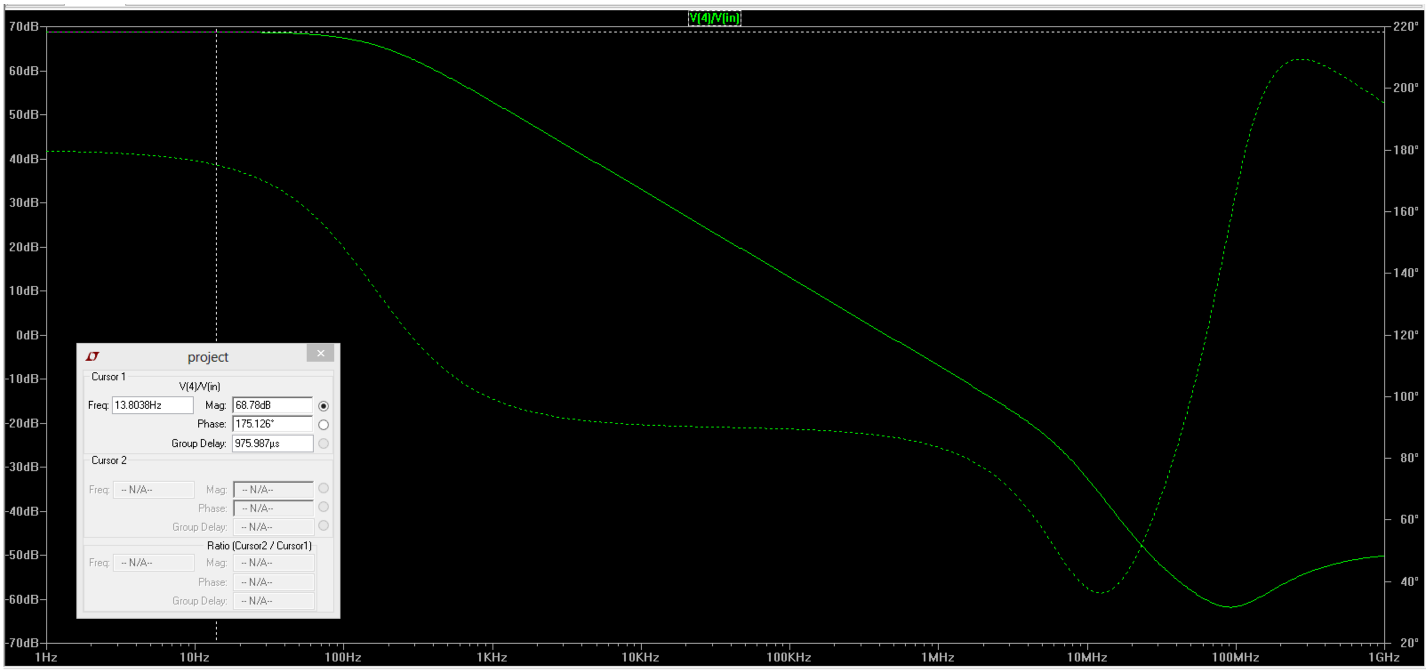
- **First stage common mode loop gain-magnitude and phase (CMFB1)**

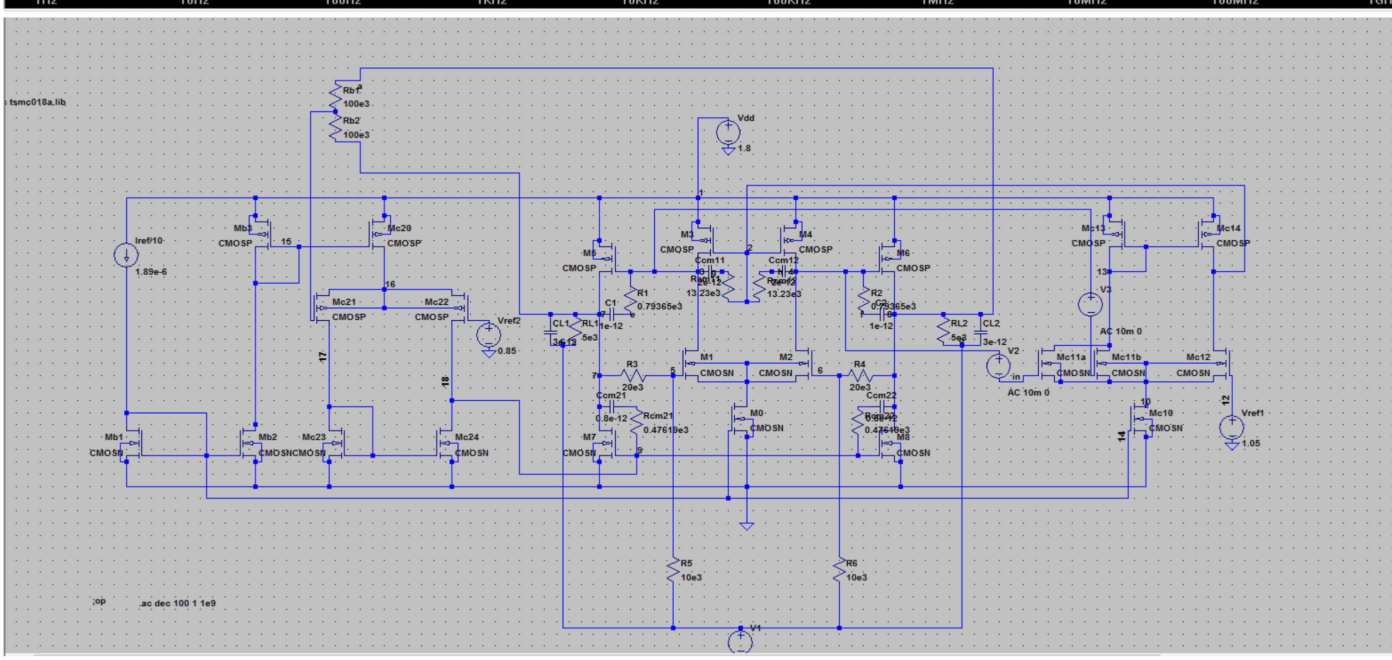
  Unity gain frequency = 446.68 KHz

  Loop Gain = 68.78 dB

  Phase Margin = 87.12 degree (plot adjusted to directly give PM)


V(4)/V(in)
70dB
60dB
50dB
40dB
30dB
20dB
10dB
0dB
-10dB
-20dB
-30dB
-40dB
-50dB
-60dB
-70dB
220°
200°
180°
160°
140°
120°
100°
80°
60°
40°
20°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
project
Cursor 1
V(4)/V(in)
Freq: 446.684KHz
Mag: -11.4384mdB
Phase: 87.1201°
Group Delay: 18.1894ns
Cursor 2
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--
Ratio (Cursor2 / Cursor1)
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--


V(4)/V(in)
70dB
60dB
50dB
40dB
30dB
20dB
10dB
0dB
-10dB
-20dB
-30dB
-40dB
-50dB
-60dB
-70dB
220°
200°
180°
160°
140°
120°
100°
80°
60°
40°
20°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
project
Cursor 1
V(4)/V(in)
Freq: 13.8038Hz
Mag: 68.78dB
Phase: 175.126°
Group Delay: 975.987µs
Cursor 2
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--
Ratio (Cursor2 / Cursor1)
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--

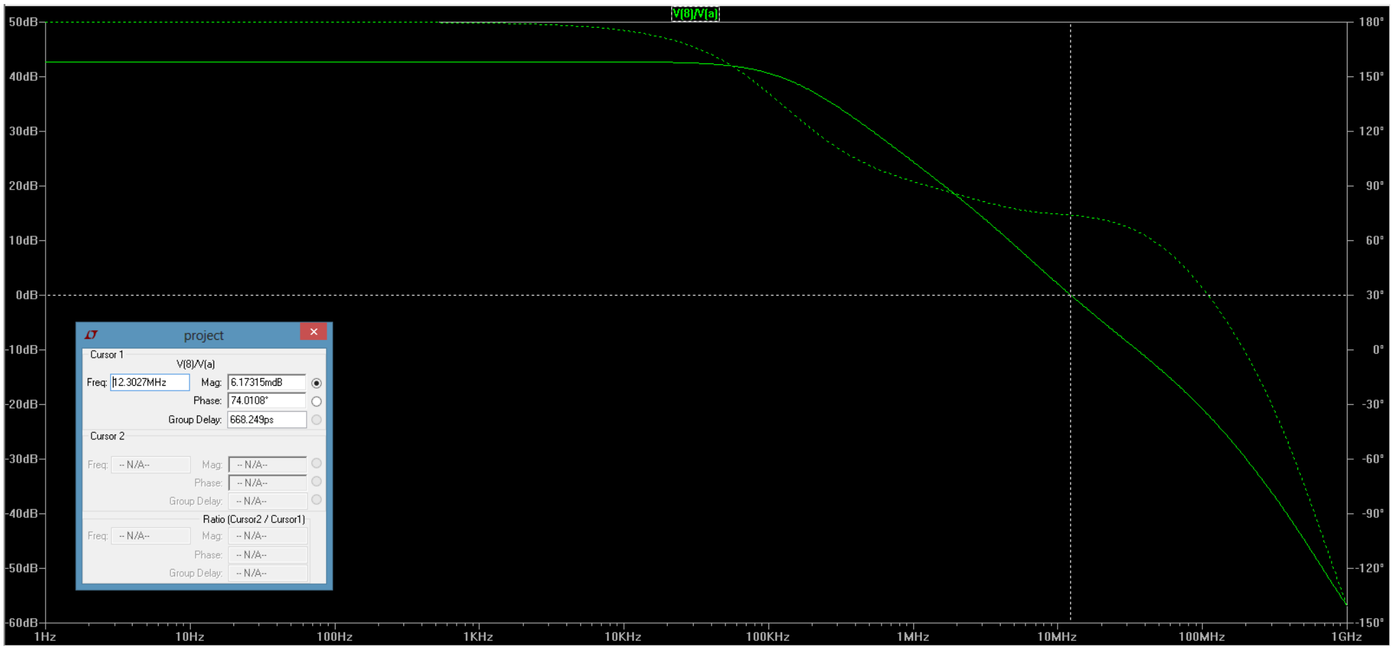

.lib tsmc018a.lib
Rb1
100e3
Rb2
100e3
Vdd
1.8
Iref/10
1.89e-6
Mb3
CMOSP
Mc20
CMOSP
Mc21
CMOSP
Mc22
CMOSP
Vref2
0.85
M5
CMOSP
M3
CMOSP
M4
CMOSP
M6
CMOSP
Ccm11
Ccm12
Rcm11
13.23e3
Rcm12
13.23e3
R1
0.79365e3
R2
0.79365e3
C1
1e-12
C2
1e-12
CL1
3e-12
RL1
5e3
RL2
5e3
CL2
3e-12
M1
CMOSN
M2
CMOSN
R3
20e3
R4
20e3
Ccm21
0.8e-12
Rcm21
0.47619e3
Ccm22
Rcm22
0.47619e3
M0
CMOSN
M7
CMOSN
M8
CMOSN
Mb1
CMOSN
Mb2
CMOSN
Mc23
CMOSN
Mc24
CMOSN
Mc13
CMOSP
Mc14
CMOSP
V3
AC 10m 0
V2
AC 10m 0
Mc11a
CMOSN
Mc11b
CMOSN
Mc12
CMOSN
Mc10
CMOSN
Vref1
1.05
R5
10e3
R6
10e3
V1
;op
.ac dec 100 1 1e9

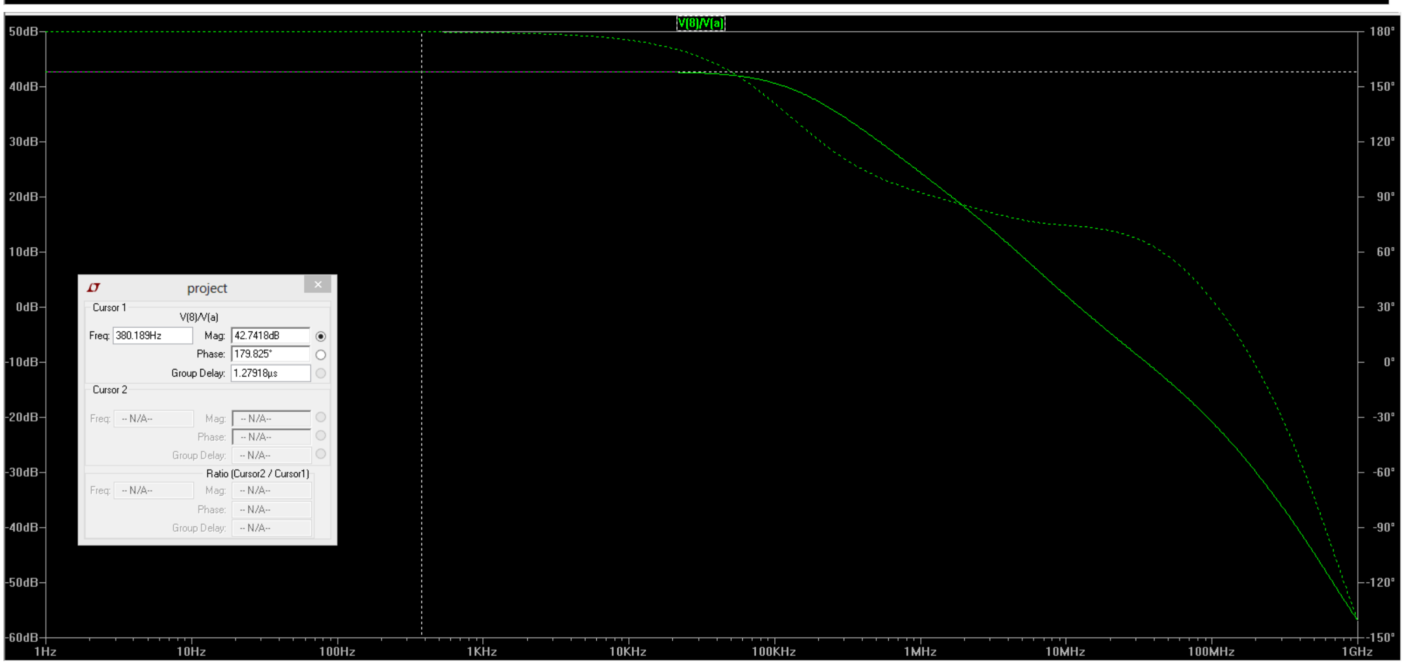
- **Second stage common mode loop gain-magnitude and phase**

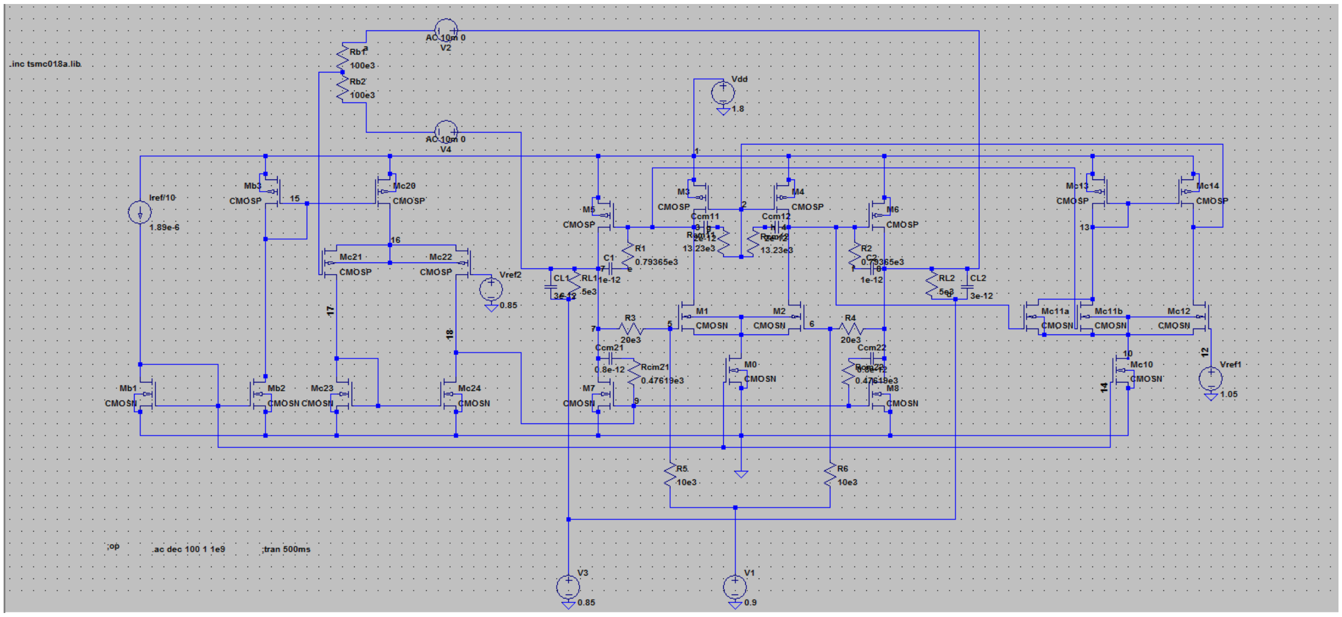
Unity gain frequency = 12.3 MHz

Loop Gain = 42.74dB

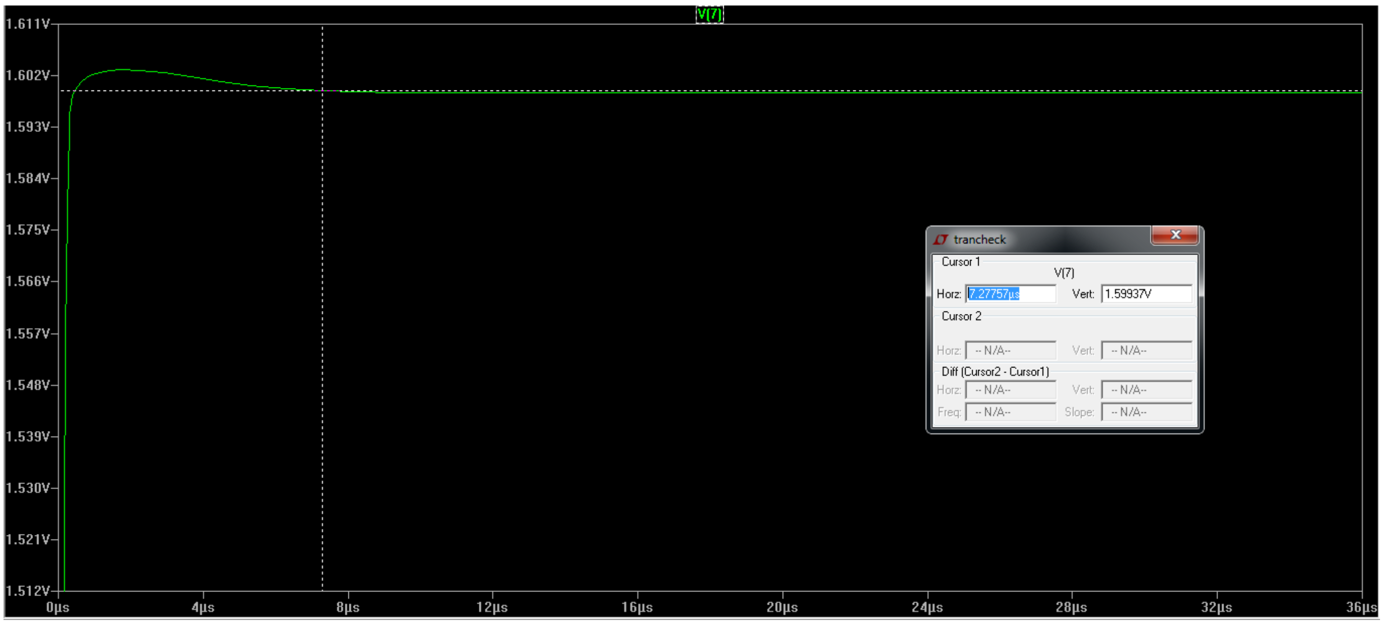
Phase Margin = 74 degree (plot adjusted to directly give PM)







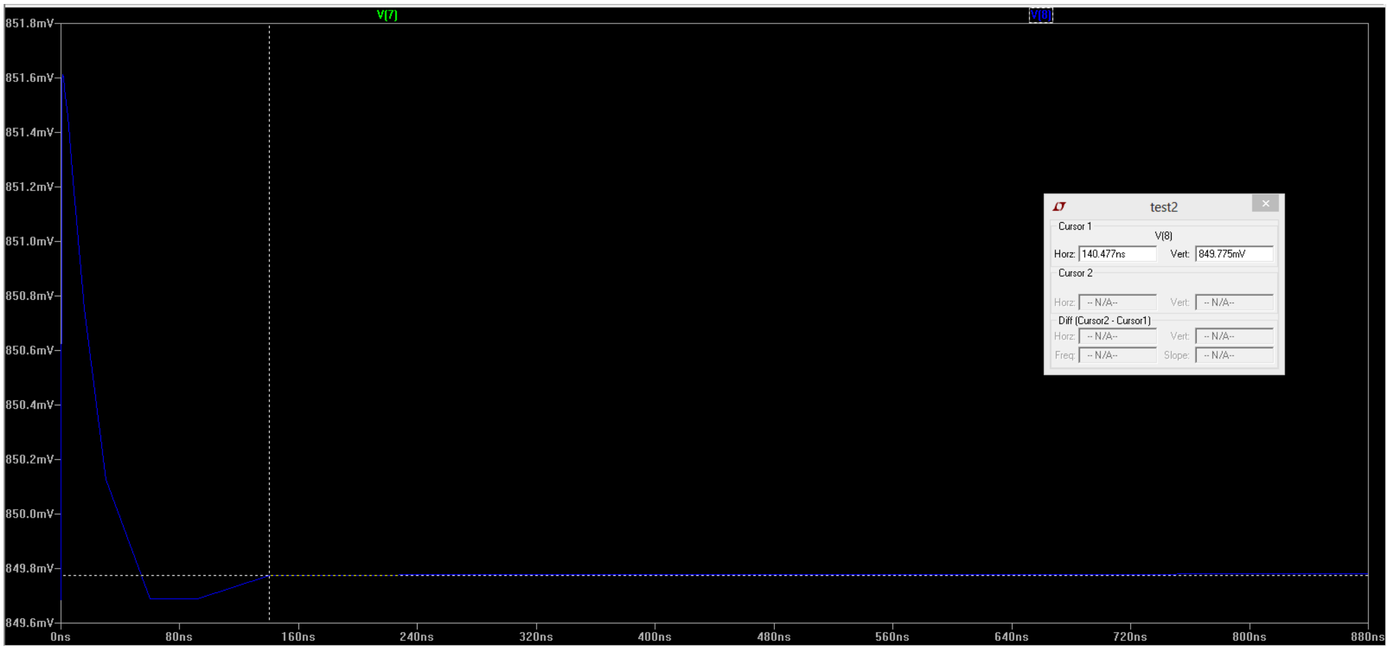
- **Transient response of the unity gain inverting amplifier with a 0.2V differential step**

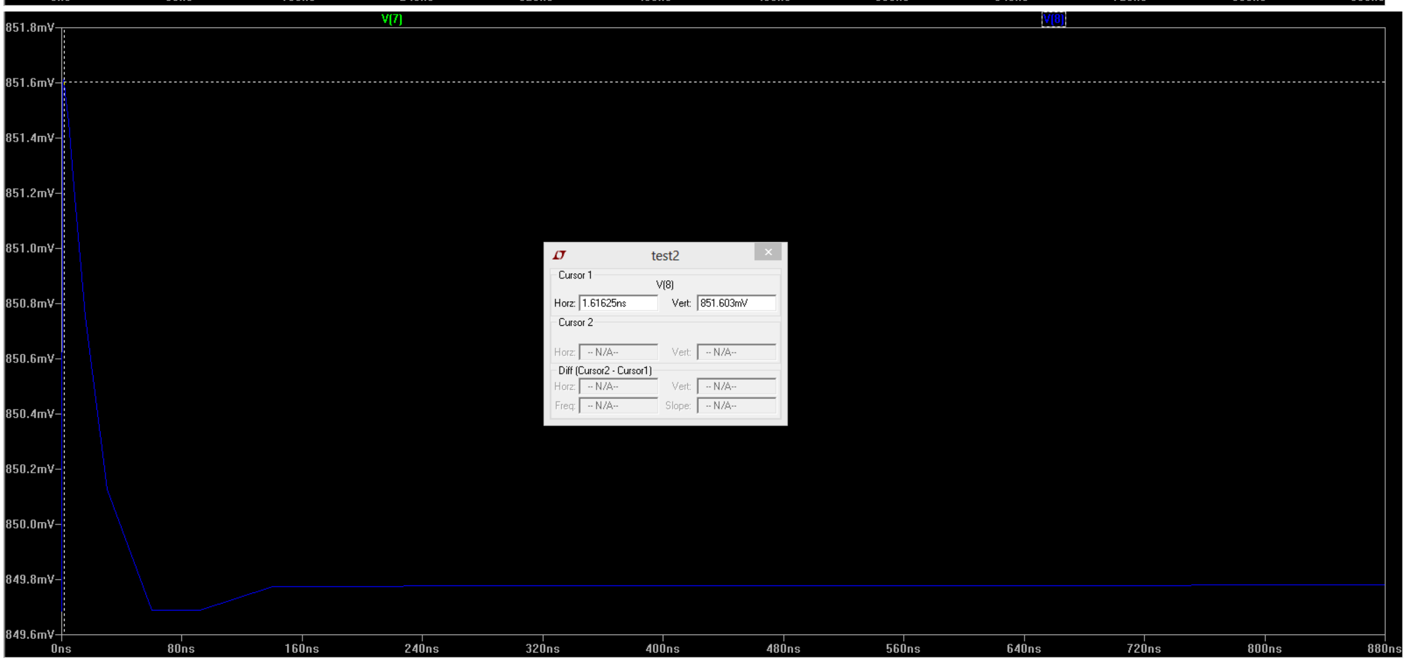


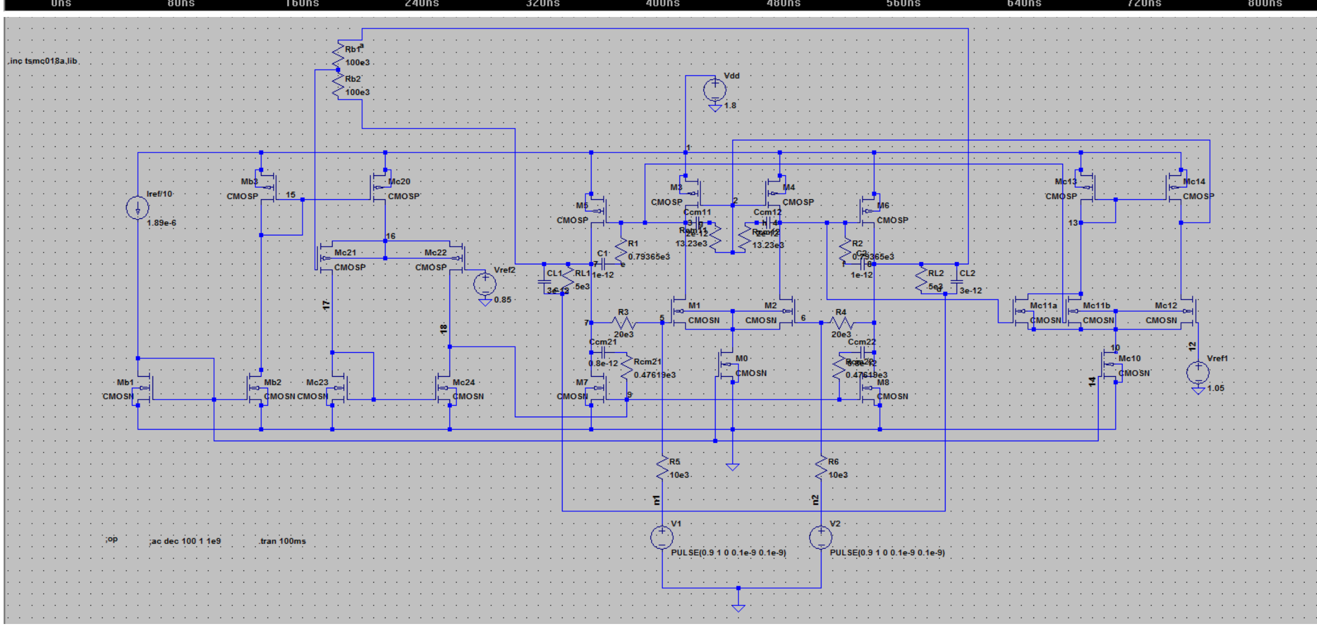
- **Transient response of the unity gain inverting amplifier with a 0.1V common mode step**

Settles in approximately 160 ns

Peak – Steady state value = 1.9 mV


V(7)
V(8)
851.8mV
851.6mV
851.4mV
851.2mV
851.0mV
850.8mV
850.6mV
850.4mV
850.2mV
850.0mV
849.8mV
849.6mV
0ns
80ns
160ns
240ns
320ns
400ns
480ns
560ns
640ns
720ns
800ns
880ns
test2
Cursor 1
V(8)
Horz: 140.477ns
Vert: 849.775mV
Cursor 2
Horz: -- N/A--
Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A--
Vert: -- N/A--
Freq: -- N/A--
Slope: -- N/A--


V(7)
V(8)
851.8mV
851.6mV
851.4mV
851.2mV
851.0mV
850.8mV
850.6mV
850.4mV
850.2mV
850.0mV
849.8mV
849.6mV
0ns
80ns
160ns
240ns
320ns
400ns
480ns
560ns
640ns
720ns
800ns
880ns
test2
Cursor 1
V(8)
Horz: 1.61625ns
Vert: 851.603mV
Cursor 2
Horz: -- N/A--
Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A--
Vert: -- N/A--
Freq: -- N/A--
Slope: -- N/A--

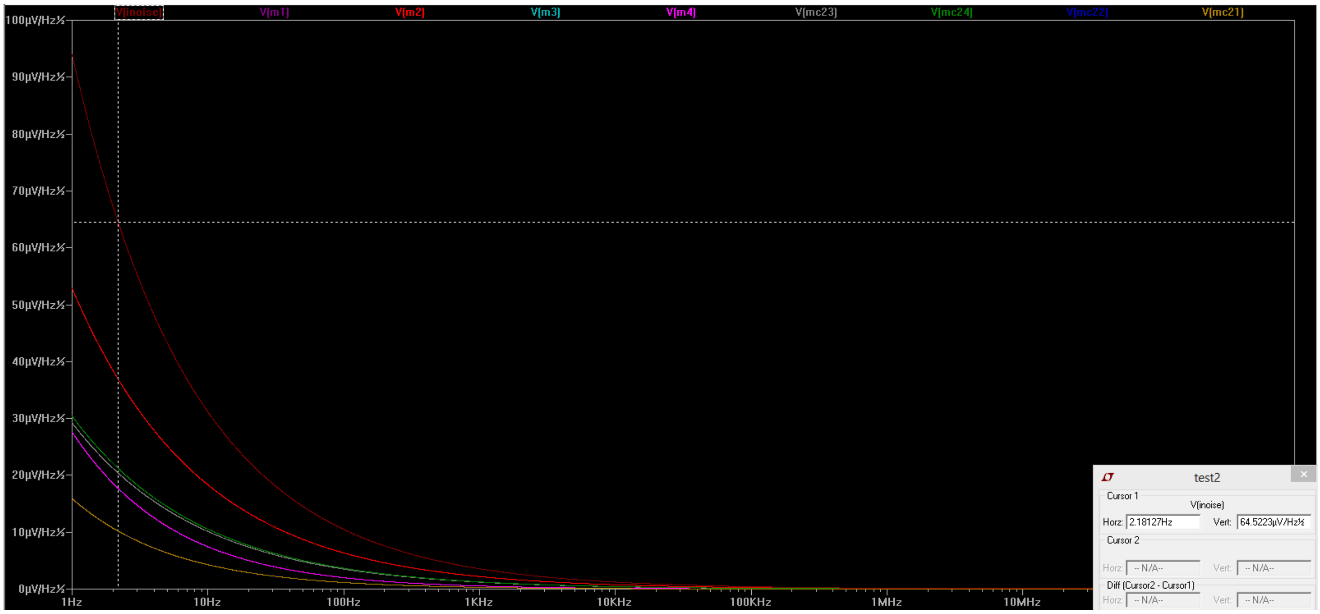

.inc tsmc018a.lib
Vdd
1.8
Iref/10
1.89e-6
Vref2
0.85
Vref1
1.05
V1
PULSE(0.9 1 0 0.1e-9 0.1e-9)
V2
PULSE(0.9 1 0 0.1e-9 0.1e-9)
;op
;ac dec 100 1 1e9
.tran 100ms

- **Input referred noise spectral density**

 1/f noise corner =

Significant noise contributions from M1, M2, M3, M4, Mc21, Mc22, Mc23, Mc24

V (input referred at 10 MHz) = 128.821nV/Hz½



Most of the values came close to what were expected from theory.

Spice Log File:

Name:	**mb3**	**mc20**	**mc22**	**mc21**	**mc13**
Model:	**cmosp**	**cmosp**	**cmosp**	**cmosp**	**cmosp**
Id:	**1.94e-06**	**5.12e-05**	**2.56e-05**	**2.56e-05**	**1.00e-06**
Vgs:	**0.00e+00**	**-4.57e-01**	**2.44e-01**	**2.39e-01**	**0.00e+00**
Vds:	**7.00e-01**	**2.43e-01**	**9.51e-01**	**9.46e-01**	**6.97e-01**
Vbs:	**7.00e-01**	**2.43e-01**	**9.51e-01**	**9.46e-01**	**6.97e-01**
Vth:	**-4.05e-01**	**-4.07e-01**	**-4.98e-01**	**-4.98e-01**	**-4.17e-01**

Vdsat:	-2.26e-01	-2.29e-01	-1.71e-01	-1.71e-01	-2.14e-01
Gm:	1.25e-05	3.13e-04	2.22e-04	2.22e-04	6.93e-06
Gds:	9.60e-08	3.20e-05	3.41e-06	3.43e-06	8.75e-08
Gmb	3.87e-06	1.01e-04	6.61e-05	6.61e-05	2.14e-06
Cbd:	1.75e-15	1.95e-13	2.36e-15	2.36e-15	4.39e-16
Cbs:	4.77e-14	1.76e-13	1.80e-15	1.80e-15	3.55e-16
Cgsov:	9.22e-16	2.56e-14	1.28e-15	1.28e-15	1.52e-16
Cgdov:	9.22e-16	2.56e-14	1.28e-15	1.28e-15	1.52e-16
Cgbov:	1.74e-18	1.74e-18	1.21e-19	1.21e-19	5.41e-19
dQgdVgb:	1.94e-14	5.49e-13	4.34e-15	4.34e-15	1.23e-15
dQgdVdb:	-8.95e-16	-4.17e-14	-1.28e-15	-1.28e-15	-1.50e-16
dQgdVsb:	-1.78e-14	-4.96e-13	-3.01e-15	-3.01e-15	-1.05e-15
dQddVgb:	-8.03e-15	-2.34e-13	-1.96e-15	-1.96e-15	-5.17e-16
dQddVdb:	2.66e-15	2.35e-13	3.64e-15	3.64e-15	5.91e-16
dQddVsb:	9.33e-15	2.60e-13	8.94e-16	8.94e-16	4.79e-16
dQbdVgb:	-3.31e-15	-8.04e-14	-4.13e-16	-4.13e-16	-1.93e-16
dQbdVdb:	-1.76e-15	-2.08e-13	-2.36e-15	-2.36e-15	-4.39e-16
dQbdVsb:	-4.94e-14	-2.26e-13	-1.85e-15	-1.86e-15	-4.20e-16

Name:	mc14	m5	m6	m3	m4
Model:	cmosp	cmosp	cmosp	cmosp	cmosp
Id:	1.01e-06	2.26e-04	2.26e-04	1.05e-05	1.05e-05
Vgs:	1.25e-02	1.92e-01	1.92e-01	4.87e-02	4.87e-02
Vds:	7.10e-01	9.50e-01	9.50e-01	7.59e-01	7.59e-01
Vbs:	7.10e-01	9.50e-01	9.50e-01	7.59e-01	7.59e-01
Vth:	-4.17e-01	-4.14e-01	-4.14e-01	-4.82e-01	-4.82e-01
Vdsat:	-2.14e-01	-2.67e-01	-2.67e-01	-1.81e-01	-1.81e-01
Gm:	6.94e-06	1.22e-03	1.22e-03	8.39e-05	8.39e-05
Gds:	8.64e-08	1.06e-05	1.06e-05	1.85e-06	1.85e-06
Gmb	2.15e-06	3.91e-04	3.91e-04	2.53e-05	2.53e-05
Cbd:	4.39e-16	8.48e-14	8.48e-14	9.66e-16	9.66e-16
Cbs:	3.54e-16	6.44e-14	6.44e-14	7.67e-16	7.67e-16
Cgsov:	1.52e-16	4.96e-14	4.96e-14	4.61e-16	4.61e-16
Cgdov:	1.52e-16	4.96e-14	4.96e-14	4.61e-16	4.61e-16
Cgbov:	5.41e-19	1.10e-18	1.10e-18	1.21e-19	1.21e-19
dQgdVgb:	1.23e-15	6.99e-13	6.99e-13	1.56e-15	1.56e-15
dQgdVdb:	-1.50e-16	-4.85e-14	-4.85e-14	-4.59e-16	-4.59e-16
dQgdVsb:	-1.05e-15	-6.36e-13	-6.36e-13	-1.09e-15	-1.09e-15
dQddVgb:	-5.17e-16	-2.92e-13	-2.92e-13	-7.07e-16	-7.07e-16
dQddVdb:	5.91e-16	1.34e-13	1.34e-13	1.43e-15	1.43e-15
dQddVsb:	4.79e-16	3.21e-13	3.21e-13	3.24e-16	3.24e-16
dQbdVgb:	-1.93e-16	-1.15e-13	-1.15e-13	-1.50e-16	-1.50e-16
dQbdVdb:	-4.39e-16	-8.48e-14	-8.48e-14	-9.66e-16	-9.66e-16
dQbdVsb:	-4.19e-16	-1.20e-13	-1.20e-13	-7.85e-16	-7.85e-16

Name:	mb1	mb2	mc24	mc23	mc12
Model:	cmosn	cmosn	cmosn	cmosn	cmosn
Id:	1.89e-06	1.94e-06	2.56e-05	2.56e-05	1.01e-06
Vgs:	5.59e-01	5.59e-01	6.11e-01	6.11e-01	5.67e-01
Vds:	5.59e-01	1.10e+00	6.06e-01	6.11e-01	6.07e-01
Vbs:	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
Vth:	3.84e-01	3.83e-01	4.87e-01	4.87e-01	4.02e-01
Vdsat:	1.36e-01	1.37e-01	9.95e-02	9.96e-02	1.30e-01
Gm:	2.14e-05	2.18e-05	3.28e-04	3.28e-04	1.18e-05
Gds:	1.08e-07	9.35e-08	1.01e-05	1.01e-05	1.03e-07
Gmb	5.99e-06	6.09e-06	8.31e-05	8.32e-05	3.36e-06
Cbd:	1.18e-15	1.11e-15	1.34e-15	1.34e-15	3.77e-16
Cbs:	1.31e-15	1.31e-15	1.49e-15	1.49e-15	4.11e-16
Cgsov:	9.88e-16	9.88e-16	1.15e-15	1.15e-15	1.98e-16
Cgdov:	9.88e-16	9.88e-16	1.15e-15	1.15e-15	1.98e-16
Cgbov:	2.11e-18	2.11e-18	1.46e-19	1.46e-19	8.23e-19
dQgdVgb:	1.95e-14	1.95e-14	3.76e-15	3.76e-15	1.78e-15
dQgdVdb:	-9.60e-16	-9.53e-16	-1.14e-15	-1.14e-15	-1.92e-16
dQgdVsb:	-1.74e-14	-1.74e-14	-2.49e-15	-2.49e-15	-1.51e-15
dQddVgb:	-8.06e-15	-8.05e-15	-1.71e-15	-1.71e-15	-7.47e-16
dQddVdb:	2.16e-15	2.08e-15	2.49e-15	2.49e-15	5.72e-16
dQddVsb:	9.34e-15	9.33e-15	7.17e-16	7.17e-16	7.31e-16
dQbdVgb:	-3.40e-15	-3.41e-15	-3.41e-16	-3.41e-16	-2.85e-16
dQbdVdb:	-1.19e-15	-1.11e-15	-1.34e-15	-1.34e-15	-3.77e-16
dQbdVsb:	-3.56e-15	-3.56e-15	-1.59e-15	-1.59e-15	-5.65e-16

Name:	mc11a	mc11b	mc10	m7	m8
Model:	cmosn	cmosn	cmosn	cmosn	cmosn
Id:	5.02e-07	5.02e-07	2.01e-06	2.28e-04	2.28e-04
Vgs:	5.58e-01	5.58e-01	5.59e-01	6.06e-01	6.06e-01
Vds:	6.19e-01	6.19e-01	4.83e-01	8.50e-01	8.50e-01
Vbs:	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
Vth:	3.84e-01	3.84e-01	3.76e-01	4.00e-01	4.00e-01
Vdsat:	1.36e-01	1.36e-01	1.42e-01	1.58e-01	1.58e-01
Gm:	5.70e-06	5.70e-06	2.19e-05	2.20e-03	2.20e-03
Gds:	3.33e-08	3.33e-08	7.27e-08	1.37e-05	1.37e-05
Gmb	1.60e-06	1.60e-06	6.10e-06	6.13e-04	6.13e-04
Cbd:	3.77e-16	3.77e-16	9.97e-15	4.45e-14	4.45e-14
Cbs:	4.11e-16	4.11e-16	1.15e-14	5.14e-14	5.14e-14
Cgsov:	1.98e-16	1.98e-16	1.98e-15	4.52e-14	4.52e-14
Cgdov:	1.98e-16	1.98e-16	1.98e-15	4.52e-14	4.52e-14
Cgbov:	1.68e-18	1.68e-18	4.27e-18	1.14e-18	1.14e-18
dQgdVgb:	3.20e-15	3.20e-15	7.44e-14	5.29e-13	5.29e-13

dQgdVdb:	-1.91e-16	-1.91e-16	-1.98e-15	-4.40e-14	-4.40e-14
dQgdVsb:	-2.83e-15	-2.83e-15	-6.77e-14	-4.58e-13	-4.58e-13
dQddVgb:	-1.32e-15	-1.32e-15	-3.06e-14	-2.21e-13	-2.21e-13
dQddVdb:	5.71e-16	5.71e-16	1.20e-14	8.90e-14	8.90e-14
dQddVsb:	1.49e-15	1.49e-15	3.78e-14	2.32e-13	2.32e-13
dQbdVgb:	-5.52e-16	-5.52e-16	-1.31e-14	-8.72e-14	-8.72e-14
dQbdVdb:	-3.76e-16	-3.76e-16	-1.00e-14	-4.44e-14	-4.44e-14
dQbdVsb:	-7.58e-16	-7.58e-16	-2.13e-14	-1.03e-13	-1.03e-13

Name:	m0	m2	m1
Model:	cmosn	cmosn	cmosn
Id:	2.10e-05	1.05e-05	1.05e-05
Vgs:	5.59e-01	5.84e-01	5.84e-01
Vds:	2.99e-01	7.42e-01	7.42e-01
Vbs:	0.00e+00	0.00e+00	0.00e+00
Vth:	3.90e-01	4.65e-01	4.65e-01
Vdsat:	1.33e-01	9.64e-02	9.64e-02
Gm:	2.44e-04	1.36e-04	1.36e-04
Gds:	2.56e-06	4.25e-06	4.25e-06
Gmb	6.83e-05	3.58e-05	3.58e-05
Cbd:	3.81e-14	5.88e-16	5.88e-16
Cbs:	4.23e-14	6.57e-16	6.57e-16
Cgsov:	9.88e-15	4.15e-16	4.15e-16
Cgdov:	9.88e-15	4.15e-16	4.15e-16
Cgbov:	1.77e-18	1.46e-19	1.46e-19
dQgdVgb:	1.67e-13	1.35e-15	1.35e-15
dQgdVdb:	-1.01e-14	-4.11e-16	-4.11e-16
dQgdVsb:	-1.47e-13	-9.00e-16	-9.00e-16
dQddVgb:	-6.95e-14	-6.14e-16	-6.14e-16
dQddVdb:	4.83e-14	1.00e-15	1.00e-15
dQddVsb:	7.82e-14	2.60e-16	2.60e-16
dQbdVgb:	-2.82e-14	-1.23e-16	-1.23e-16
dQbdVdb:	-3.86e-14	-5.87e-16	-5.87e-16
dQbdVsb:	-6.12e-14	-6.93e-16	-6.93e-16